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Best Army Practices for Acquiring & Fielding Highly Reliable Systems

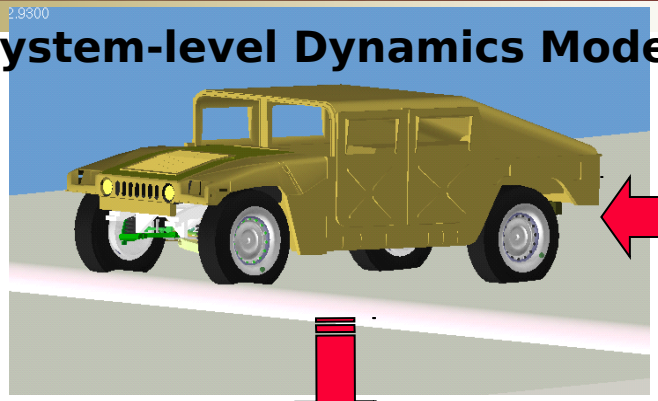
David E. Mortin, Ph.D.
410.278.6248
david.mortin@us.army.mil

Outline

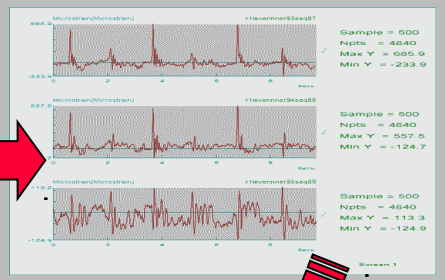
- Reliability Engineering & Physics-of-Failure (PoF) for vehicles and mechanical systems
- Reliability Engineering and PoF for electronics
- Other reliability best practices
- Summary

PoF Analysis Overview

System-level Dynamics Model

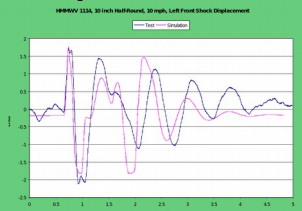


Live Data from Instrumented Tests

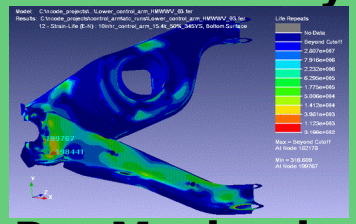


Strains, Accelerations, Displacements

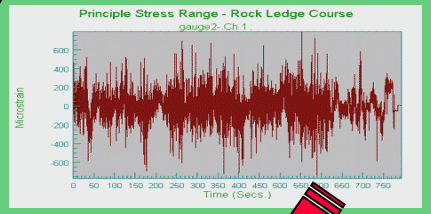
Loads, Acceleration



Finite Element Analysis (FEA)

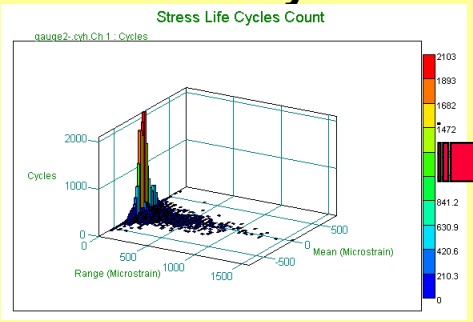


Strain Time

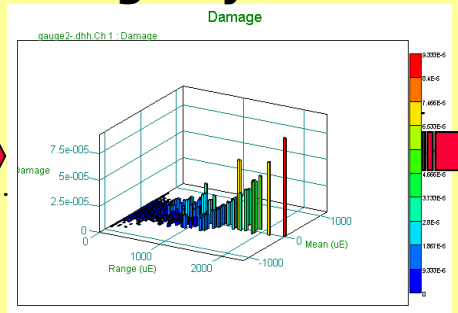


FEA tools, e.g. Pro Mechanica, ANSYS, NASTRAN

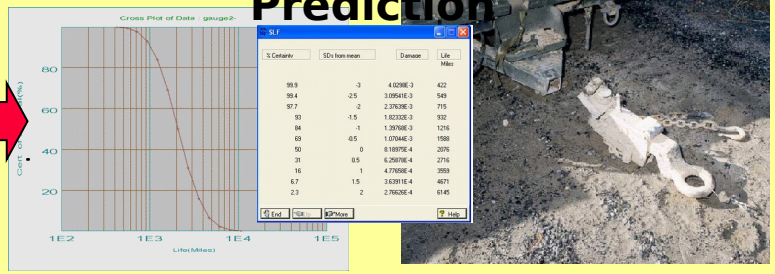
Rainflow Cycles



Damage Cycles Count



Component Life Prediction



Computational fatigue analysis using nCode tools and BS7608 or similar standa

Rapid Application of M&S

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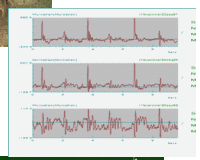
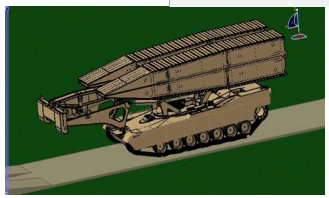
RESOURCES

CAD tools

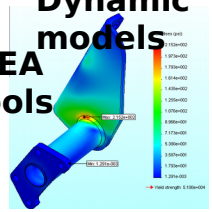
Test data



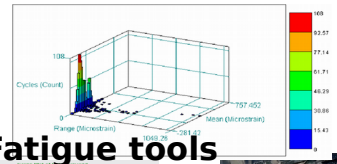


Dynamic models

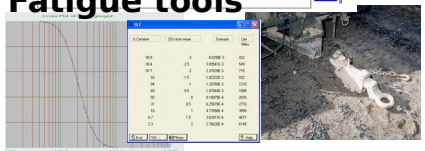
FEA tools



MSRC

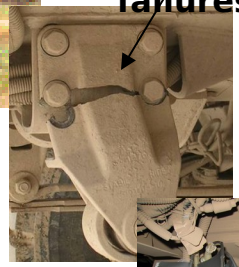


Fatigue tools

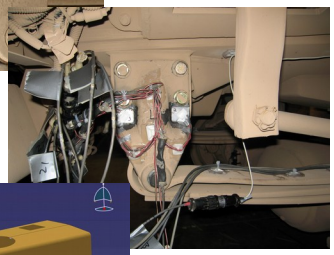


PROGRAMS

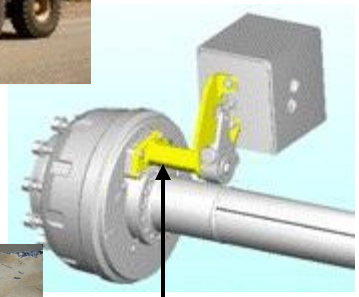
Leaf spring bracket failures

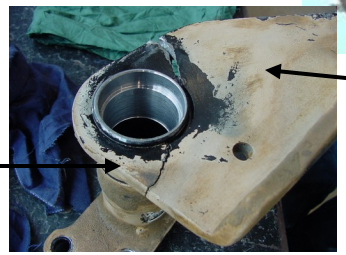


Test data



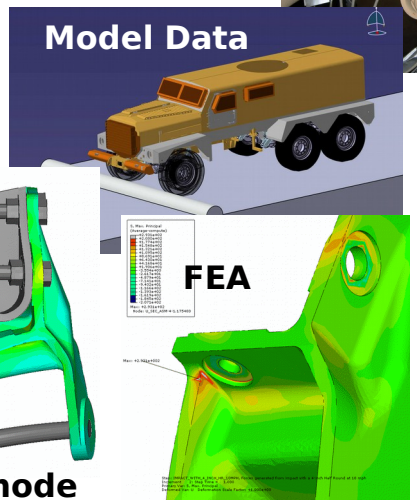
Rear Axle End





Brake Chamber Bracket

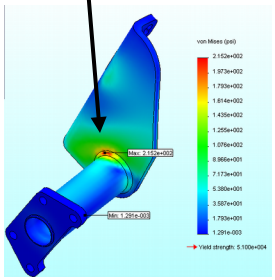
Failure Location

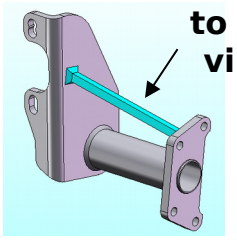


Model Data

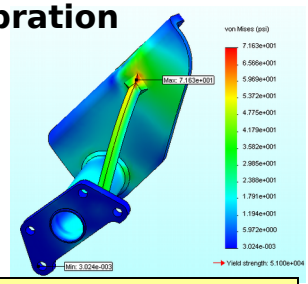
FEA

Failure mode identification





Solution – strut to prevent vibration



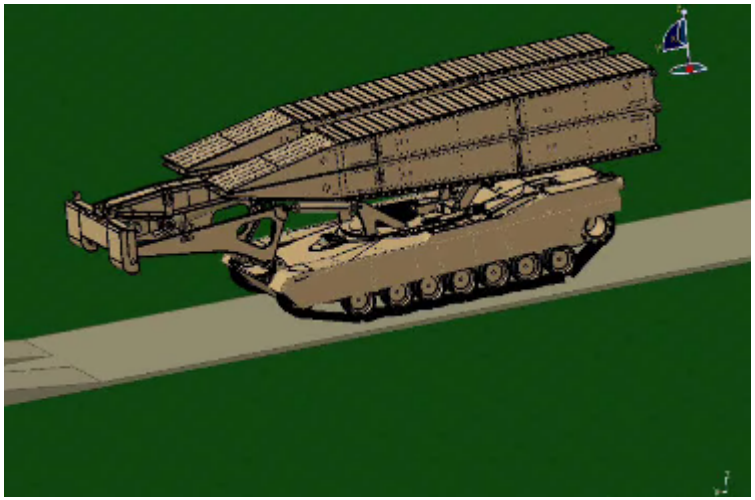
Working w/USMC leads to develop solution

Fix verified by M&S and testing; will be applied to 1st version vehicles

Tracked System M&S

Background

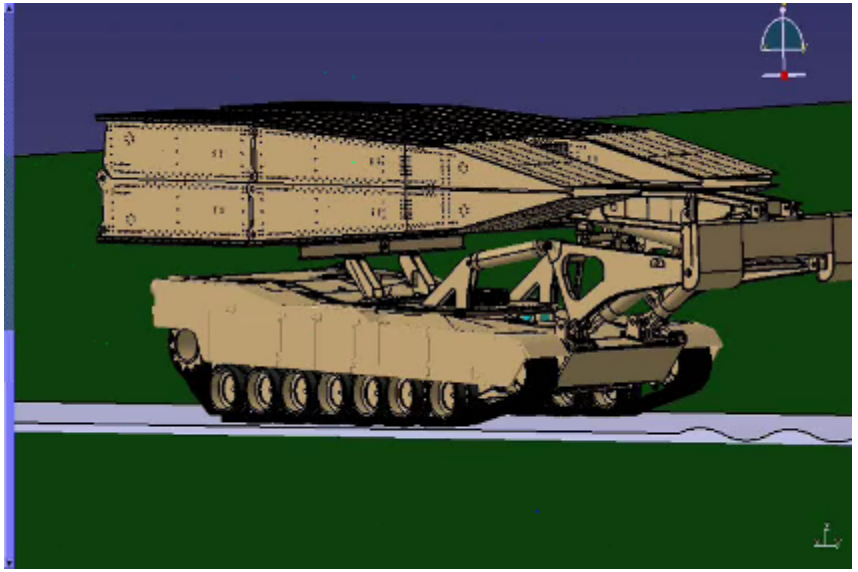
- Joint program between the US Army and US Marine Corps to mount an existing bridge on a tracked vehicle chassis
- To accommodate the bridge, the turret is removed and a launching system is mounted toward the front of the chassis
- The bridge and launcher system shift the center of gravity of the vehicle forward giving the platform a significantly different weight distribution than the existing track vehicle.



M&S

- Dynamics model of system developed within Virtual Lab Motion
- Physical testing of system completed
- Verification of model completed during January 08
- Virtual terrain developed and virtual testing of model performed
- Model calibrated using physical test data
- Model shows good agreement w/ physical test data

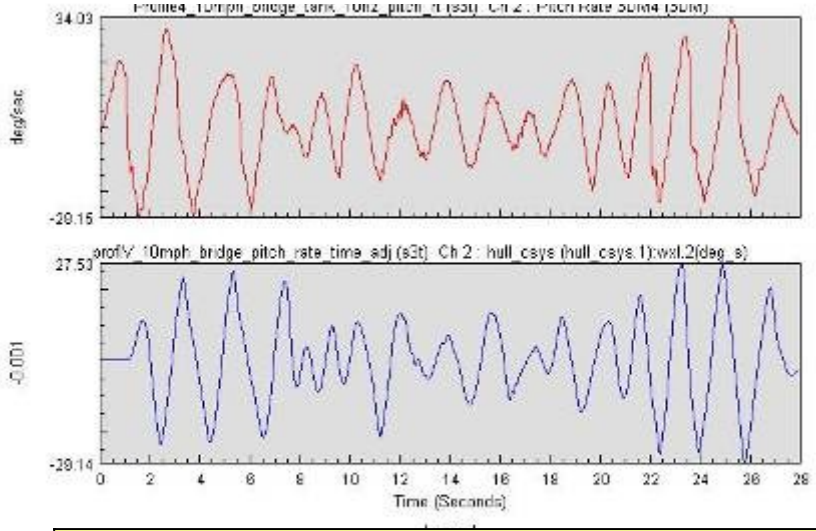
Washboard Course at 10 mph Video



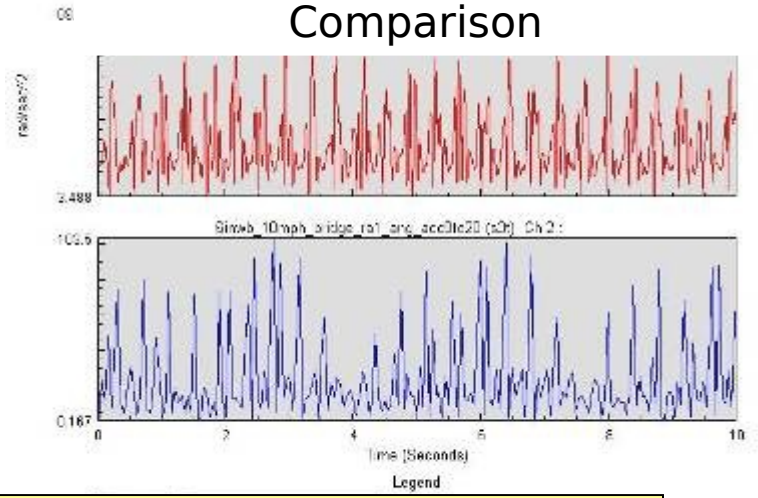
Model Validation Results & Analysis

- Model hull motions (accelerations, pitch rates) show good agreement w/ test data over all test courses
- Roadwheel/roadarm motions (vertical and angular accelerations) show reasonably good agreement w/ test data over most sections of the test courses

Hull Pitch Rate Comparison



Roadarm Angular Acceleration Absolute Value Comparison

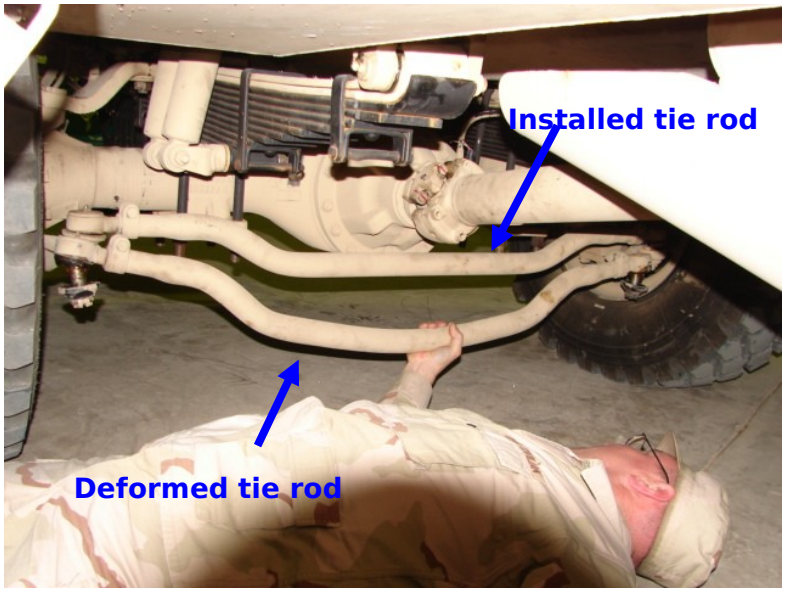


- Model for supporting quick-reaction engineering decisions
- Model for reducing test-fix-test cycles

Vehicle Component Failure Analysis

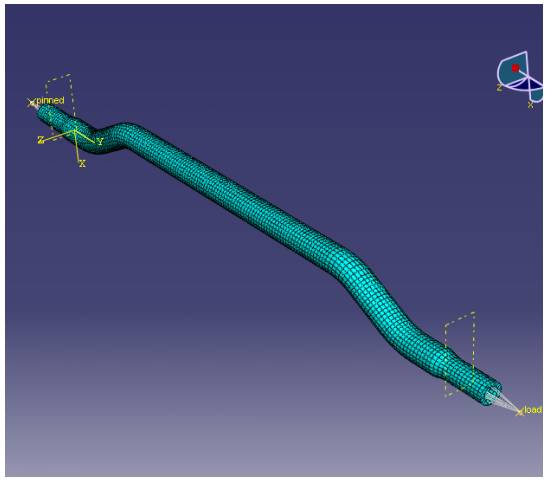
- Tie rod sustained damage during driver training
- No indication that the tie rod was struck by an object
- Driver training course below left
- Damaged tie rod being held alongside good tie rod for comparison below right

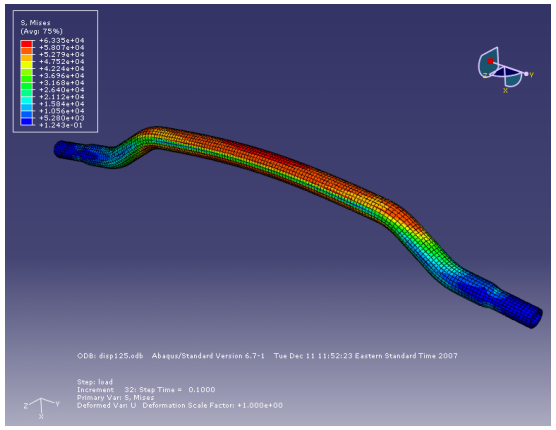
Vehicle operating in training area



Comparison of failed and installed tie rod

Failure Analysis Results





- Conclusions-
  - Most likely cause of failure attributed to buckling
  - Deformed shape consistent with axial compressive loading applied through ball joint ends
  - Modeling analysis reveals critical load ~10K lbs
  - Dynamics modeling shows vehicle loading capable of causing buckling.

Analysis supports efficient design, test, and development of best reliability improvement strategies

Other Mechanical PoF Examples

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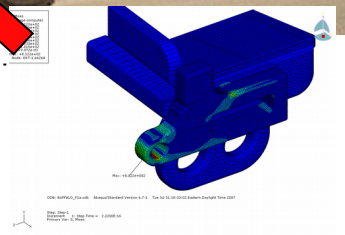
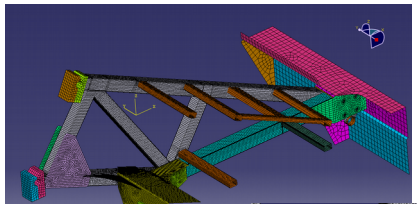
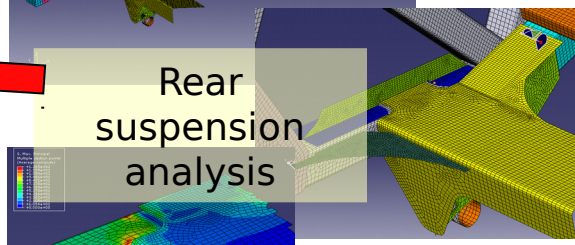
Tow eye analysis







Rear suspension analysis

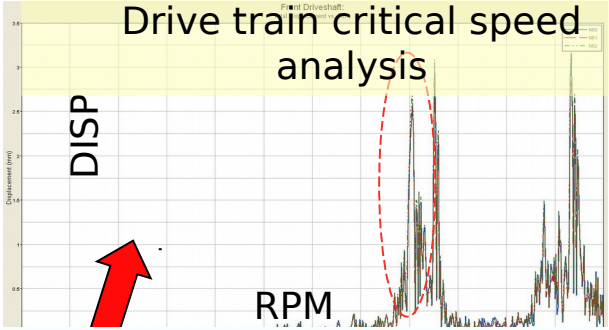
Pinned Constraints

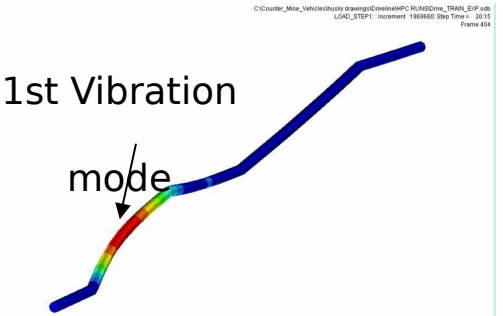
Applied Rotation

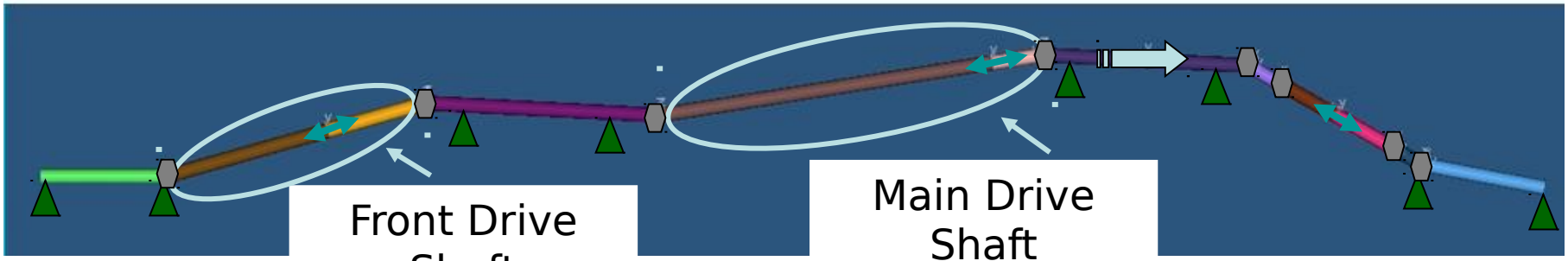
Slider Joint

Universal Joint

Drive train critical speed analysis







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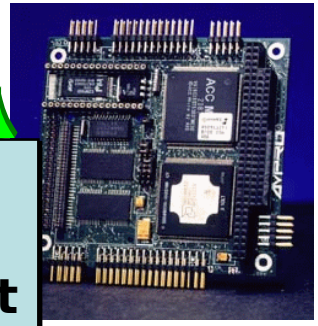
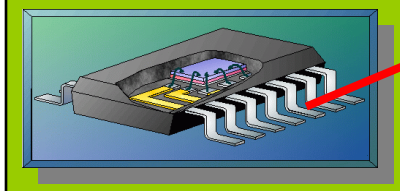
Electronic Physics of Failure

Stress (e.g., vibration) is propagated from system level to failure site



- A.K.A. Physics of Failure, Predictive Technology, Predictive Engineering, Physics of Reliability
  - -Model the root causes of failure (e.g., fatig fracture, corrosion & wear)
- Failure models & CAD tools developed
  - - By industry/academia/government
  - - To address specific materials, sites, & architectures



Failure root-cause is cracking of solder joint

Benefits

- **Design-in reliability**
- **Eliminate failures prior to test**
- **Better chance of passing test**
- **Increased fielded reliability**
- **Improved prognostics**
- **Decreased O&S costs**

Physics-of-Failure Process for Electronics

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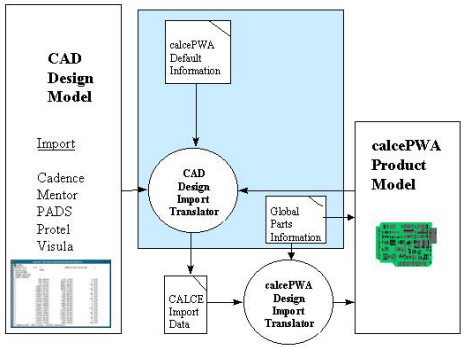
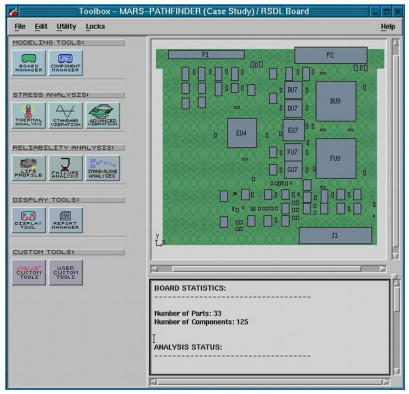
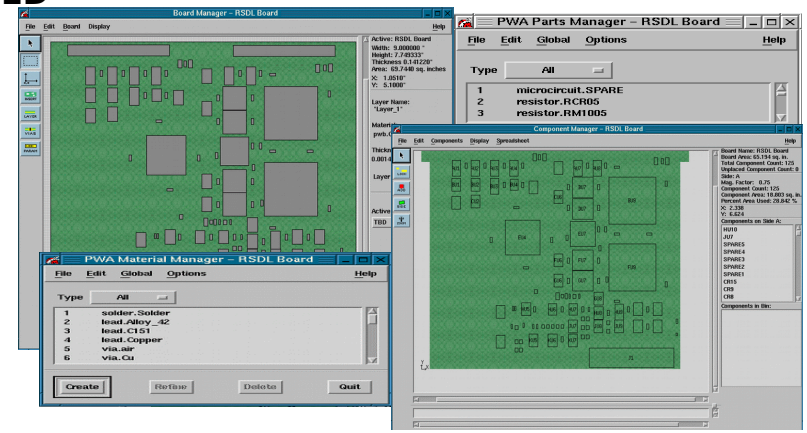


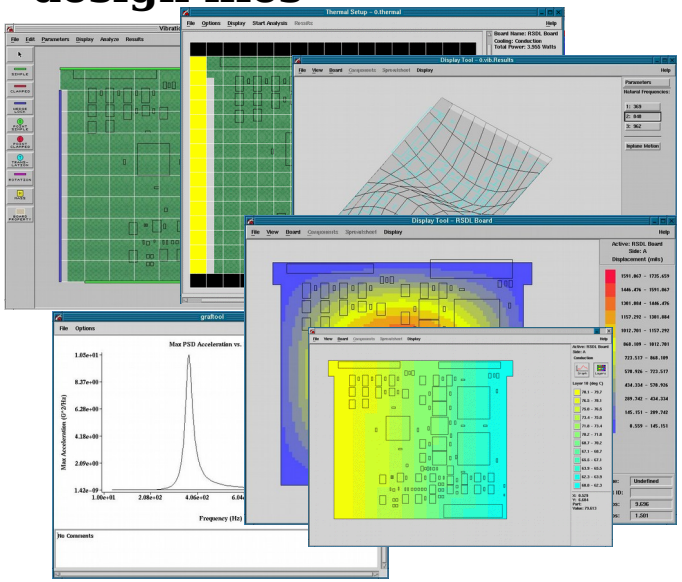
Support for importing CAD design files


Toolbox – MARS–PATHFINDER (Case Study) / RSDL Board
BOARD STATISTICS:
Number of Parts: 33
Number of Components: 125
ANALYSIS STATUS:

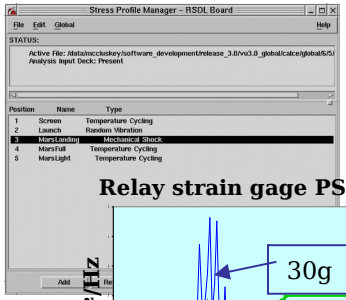
Toolbox



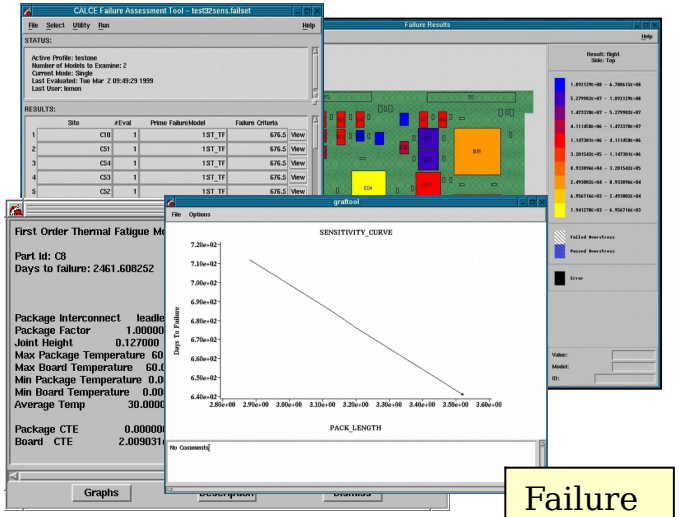
Product Modeling and Databases



Load Transformation


Stress Profile Manager – RSDL Board
Relay strain gage PSD @ 25c
30g
20g
Figure D.11 - MPF Lander IEM Temperature During Sols 33 & 34

Environment Characterization



Failure Risk Assessment & Sensitivity Analysis

Failure Model Plug-ins

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•CALCE is the largest electronic products and systems research center focused on electronics reliability, is dedicated to providing a knowledge and resource base to support the development of competitive electronic components, products and systems

Members

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- ES&T
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- Argon ST, Inc.
- Emerson
- ReliaSoft Corp
- Sun Microsystems, Inc.
- ERS, Inc.
- ES&T
- Faraday Technology
- Argon ST, Inc.
- Emerson
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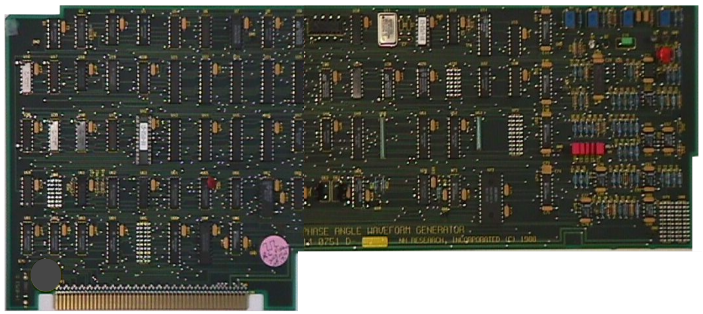
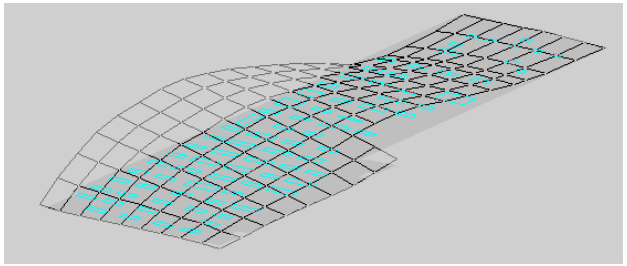
- Samsung Techwin Co. Ltd.
- Samsung Electro-Mechanics
- Samsung Mechatronics and Manuf. Technology Center
- Samsung Memory Division
- Toshiba
- Aero Combined Environmental Lab
- Naval Surface Warfare Center
- Sandia National Labs
- U.K. MOD
- U.S. Army Research Lab
- Aavid Thermalloy
- GE
- GE Healthcare Technologies
- Grundfos Management
- Qualmark
- Schlumberger Oil Drilling Services
- Seagate Technology
- Siemens
- Whirpool
- Arbitron
- Ericsson AB
- Instituto Nokia de Technologia
- Nokia
- Research In Motion, Lt

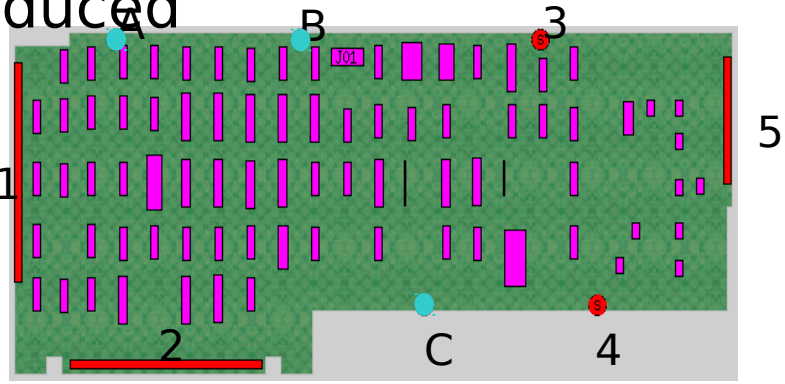
Example - Army Power Supply





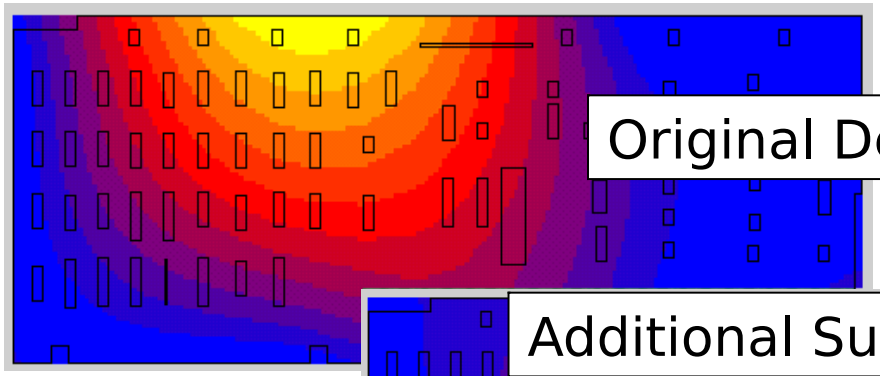
Vibration Response

- Analysis showed that additional supports could significantly increase life
- 1st Natural frequency of circuit card increased from 35 Hz to 125 Hz
- Board displacements and component stresses drastically reduced

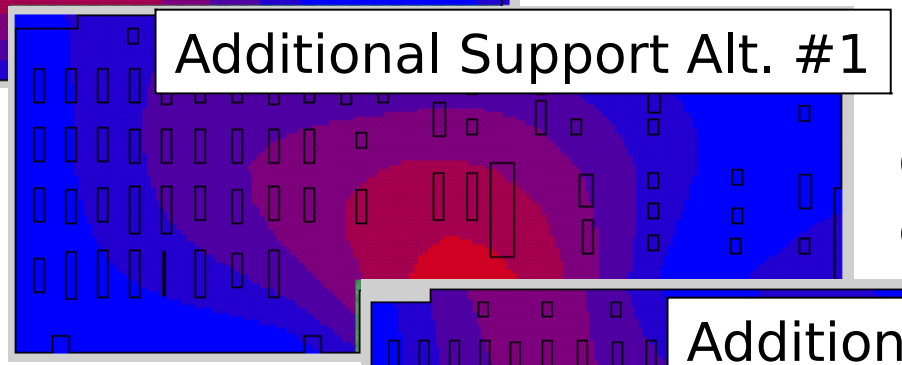


Circuit Card Model

Army Power Supply Analysis – Minimal Cost to Improve Reliability

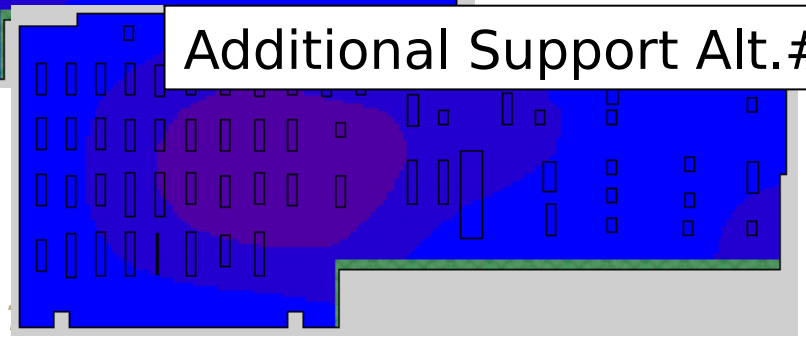


Original Design

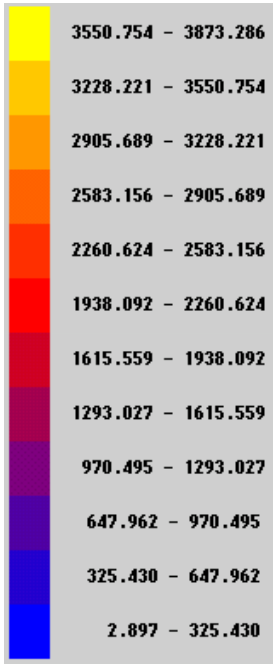


Additional Support Alt. #1

Additional Support Alt. #2



Additional Support Alt.#3

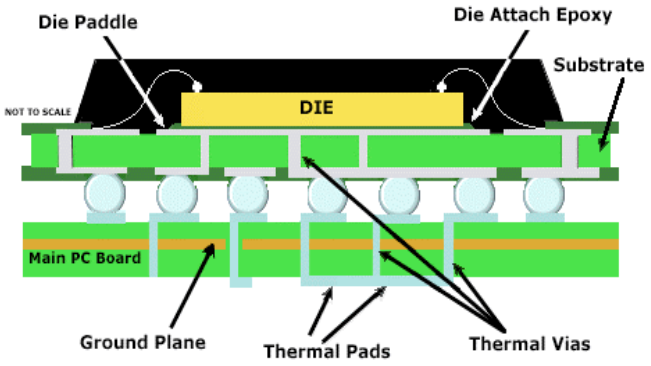


- 1st Natural frequency of circuit card increased from 35 Hz to 125 Hz
- Board displacements and component stresses

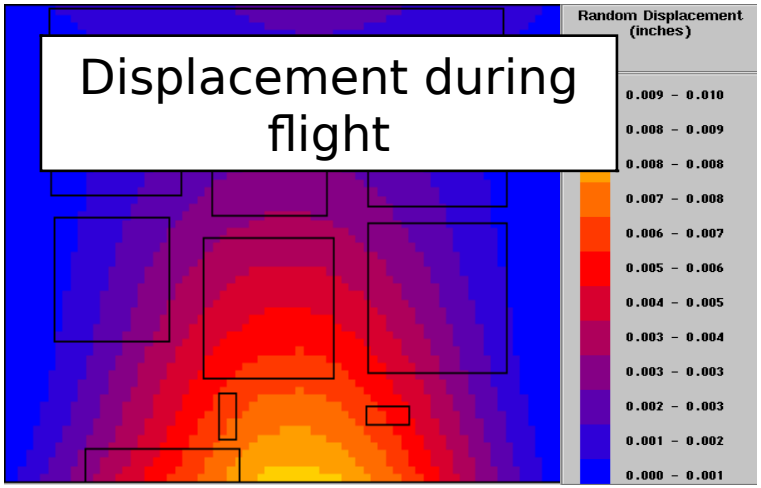
- Analysis showed that additional supports could significantly

Ball-Grid Array for Army Missile

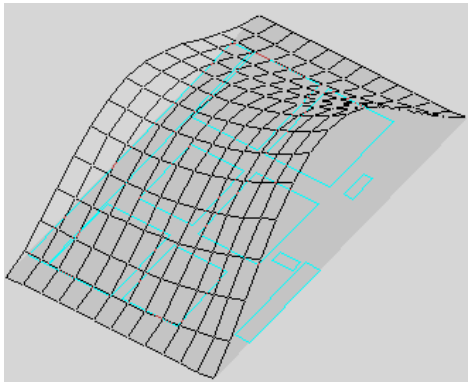
- Desirable to use Ball Grid Array (BGA) packages in Army Missile
- Concern that failure could occur because of thermal and vibration stresses
- Physics-of-Failure analysis to calculate expected life of BGA packages

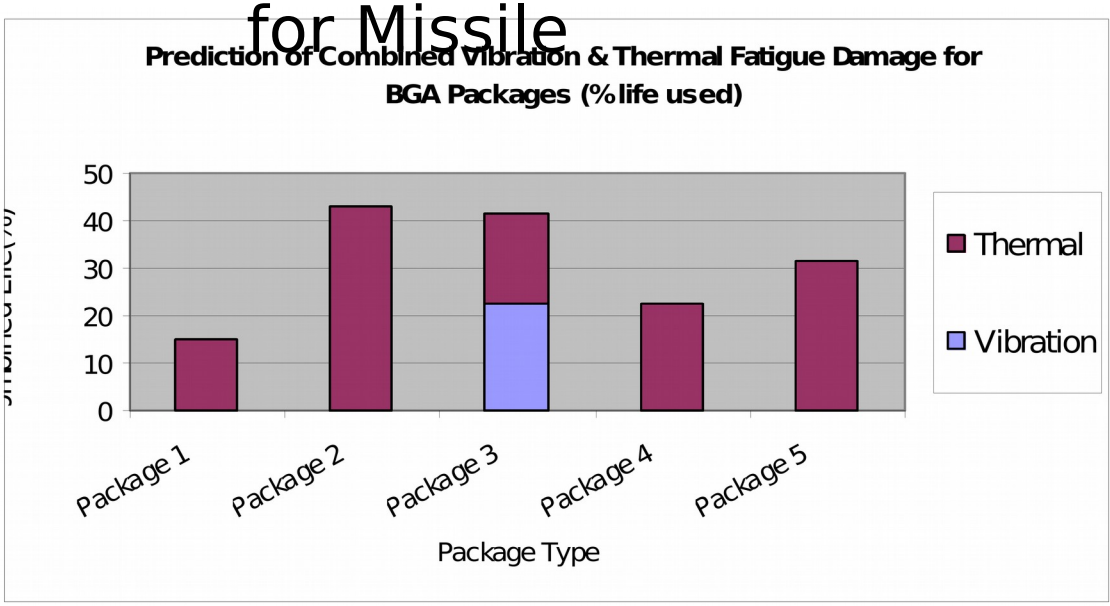


Ball Grid Array Physics-of-Failure Analysis



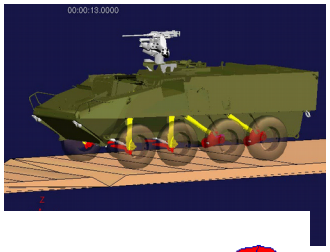
- Reduced Risk
- Results Confirmed with Accelerated Testing
- BGA Packages Appropriate for Missile



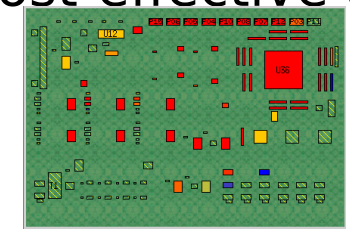


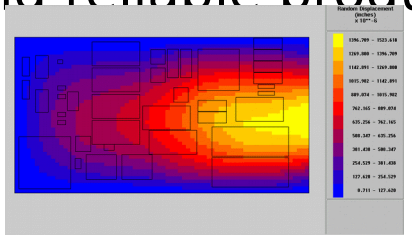
Best Practice: Cost Effectively Implementing Reliability Improvement Analyses and Testing

- The supplier & gov't do not equate increases in reliability with huge increases in cost. In many cases, significant improvements in reliability can be achieved at minimal cost, especially when reliability improvement is addressed as part of the design process. Suppliers that see reliability increasing only through a test-fix-test-fix-test process will likely not produce a cost-effective and reliable product.

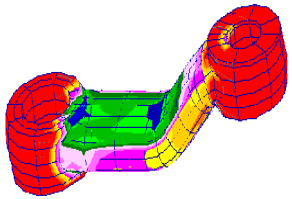


Dynamic Analysis Model for Entire Structure $300K-$500K

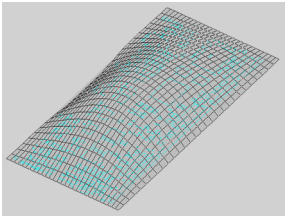




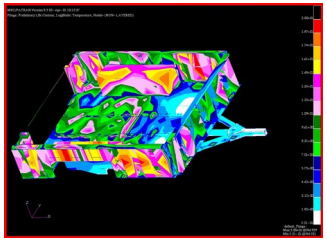
$20K a Circuit Card for Physics-of-Failure Thermal & Vibrations Analysis



Finite Element Analysis $50K-$100K per Component



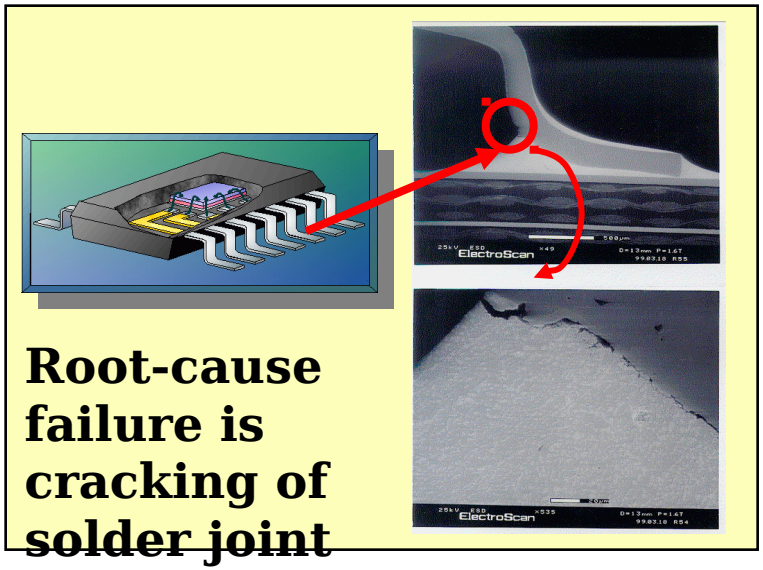
- ***Reliability best practices are relatively inexpensive***
- ***Such analyses can result in equipment getting into the hands of the Warfighter quicker***



Fatigue Analysis $50K per Component

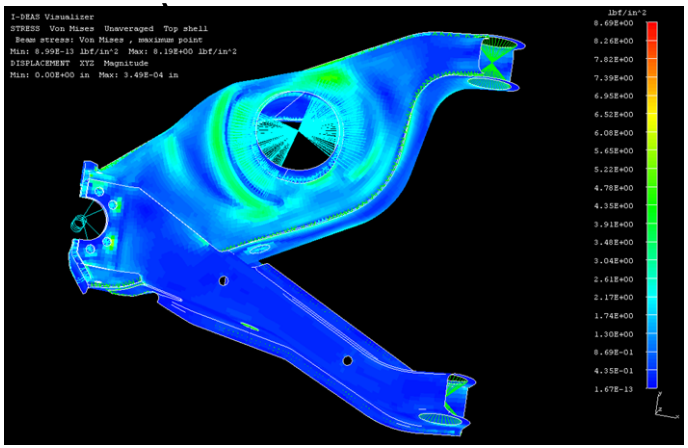
Best Practice: Having an Integrated Approach to Design Out Failures Early

- The supplier routinely conducts thermal and vibration analyses to address potential failure mechanisms and failure sites (i.e., a physics-of-failure approach to reliable design). These analyses would likely include the use of fatigue analysis tools, finite element modeling, dynamic simulation, heat transfer analyses, etc. Overall, the supplier should have an integrated approach to design out many failures early in the development process.



Root-cause failure is cracking of solder joint

Model the root causes of failure (e.g., fatigue, fracture, corrosion &



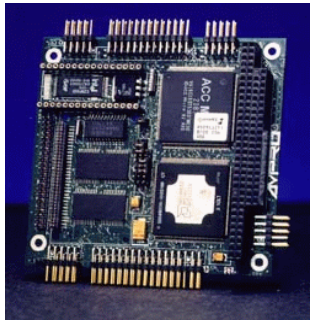
Models and low-level testing methods exist and are routinely used by reliability leaders

Best Practice: Characterizing Component Loads and Stresses

The supplier has characterized the critical loads and stresses. A good design team will characterize the life cycle environment and operational duty cycle stresses that their components will see. Sometimes this will require additional testing and data collection. Without knowing the environment that a given component will see, or at least some reasonable bounds for the usage environment, a design team cannot be confident that a given component will be reliable.

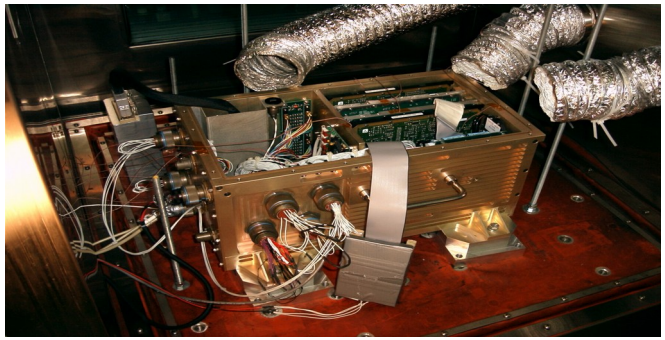
Stress (e.g., vibration) is propagated from system level to failure site

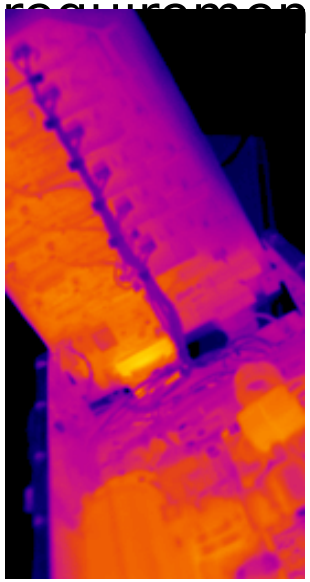
Designing for high reliability requires knowledge of the loads and stresses that components will experience (their actual boundary conditions)

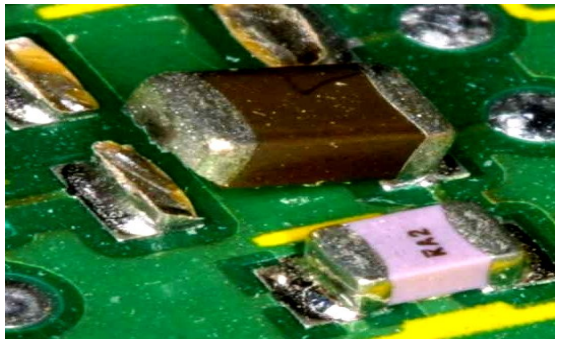


Best Practice: Conducting Low-level Testing

The supplier routinely conducts low-level testing starting very early in the development process. The supplier also conducts significant integration testing. The supplier should routinely share these results, along with the results of the failure mechanism modeling described above, with the customer to demonstrate and provide progressive assurance that the development program is on track to produce a system that meets the specified reliability requirements.

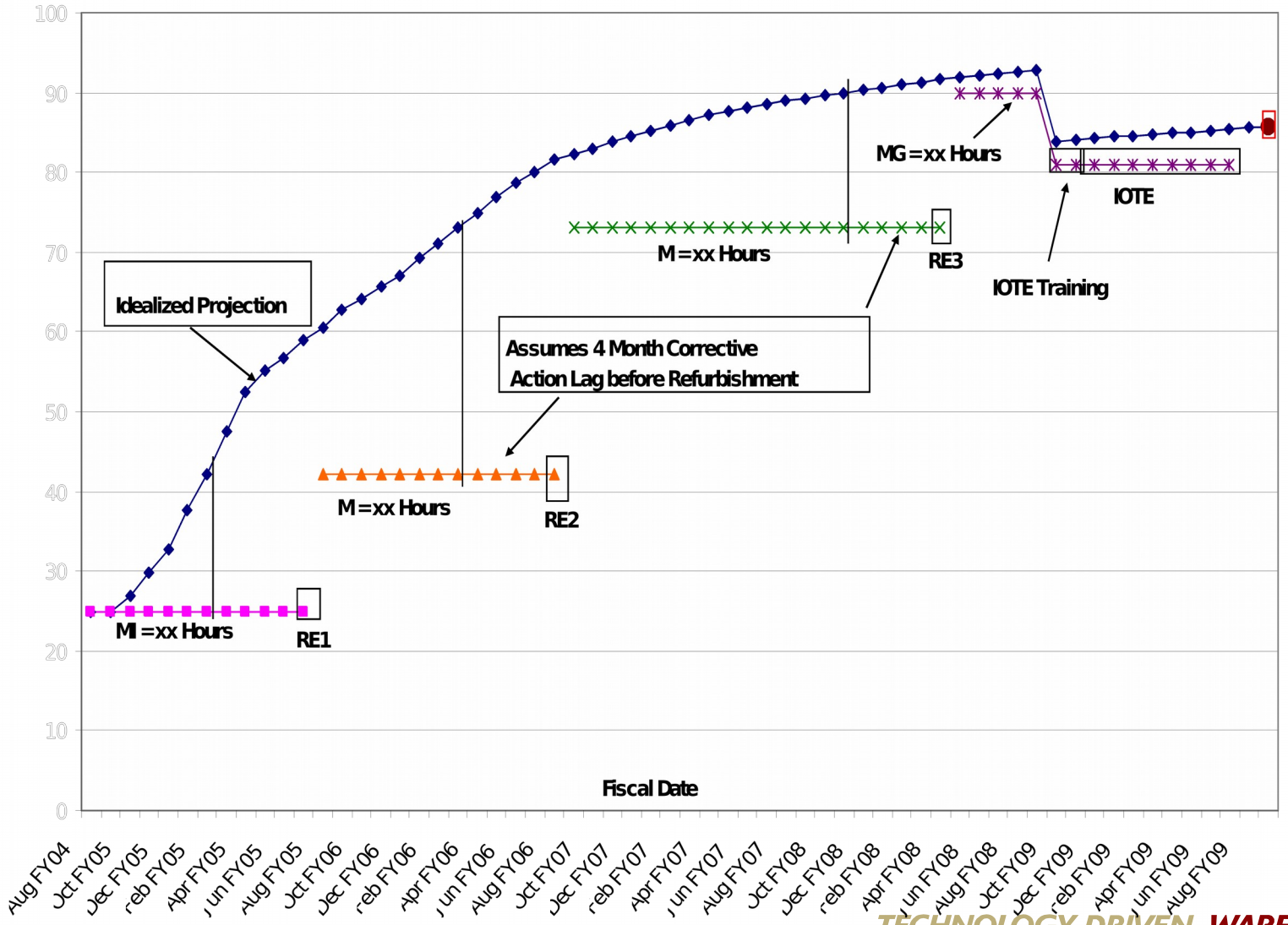






- For each mission type, develop detailed fault tree with the initiating events at the lowest possible level
  - Qualitative: Color code events to determine areas of risk. Green – detailed engineering assessments and low indenture level testing conducted with little chance of failure; Red – lack of enough engineering analysis and low indenture level testing & there is a moderate potential for failure; Yellow – risk between red and green.
  - Quantitative – populate initiating events with failure probabilities based on engineering analysis (not handbook predictions) and results from all testing. For many failure modes, cycles/hours can be combined to produce a crude lower bound

Best Practices – Realistic Reliability Program Schedule



- Detailed planning needed (like this example)
- Some programs just use reliability growth planning model curve without matching curve to asset availability and refurbishmen

Best Practice: No Handbook-based Reliability Predictions

- Many reliability numbers shown in briefings and analyses are based on reliability predictions developed from MIL-HDBK-217, PRISM, or other reliability prediction handbooks.

- Handbook input data are outdated and do not consider critical factors that actually influence reliability such as when temperature is below a critical value or temperature cycling.

- Many product failures are not the result of constant rate failure mechanisms

- In many cases, reliability predictions are not really necessary. If deemed critical for a given application use (in order shown):
  - Data from similar systems
  - Engineering analysis
  - Subject matter experts

Best Practice:
No Handbook-based Reliability Predictions

RADIO TEST

VENDOR	MIL-HDBK-217 MTBF (HOURS)	ACTUAL TEST MTBF (HOURS)	RATIO OF PRED TO ACTUAL
A	811	98	8.3
B	1269	74	17.1
C	1845	2174	.8
D	2000	624	3.2
E	2000	51	39.2
F	2304	6903	.3
G	2450	472	5.2
H	2840	1160	2.4
I	3080	3612	.9

Summary

- PoF M&S and reliability best practices can provide increased understanding about design behavior and the root causes of hardware failure.
  - Testing can tell you it failed
  - PoF can tell you why it failed
- Private sector leaders heavily invest in M&S technologies; benefits are proven.
- Insights provided by PoF M&S and reliability best practices can make the Government a smart consumer.
- Return-on-Investment (ROI) very high. Benefits include reduced O&S costs, increased reliability, and availability.
- PoF and best reliability and analysis techniques can accelerate fielding and reduce overall testing.
- Often no additional costs required to implement; odds are funds required to support PoF & M&S are already being applied to traditional engineering analyses, test-fix-test cycles, or to maintain inefficient unreliable hardware.